Chapter 5

ASSESSMENT OF THE IMPACT OF *IN SITU* BURNING ON RESPONSE CAPABILITY

In this chapter:

- *How far have* in situ *burn techniques and equipment, as well as supporting spill surveillance technology, advanced since the Caps were formulated? Have these techniques and equipment been operationally tested and proven?*

- *Are modern* in situ *burn equipment and systems readily available? What oil removal capability is represented by current inventory? How fast can pre-staged fire-resistant booms be transported to specific regions, and what oil removal capacity does this provide in each region at Tiers I, II, and III?*

- *How has the policy on* in situ *burn implementation changed over the past few years, as reflected in current agreements between federal and state agencies regarding its use?*

- *Is including a requirement and/or offset for an* in situ *burn removal capability practicable in light of the advances in technology, market availability, overall distribution of* in situ *burn resources around the nation, and current (and projected) Regional Response Team (RRT) policy for* in situ *burn implementation?*

To assess the implications of *in situ* burning with respect to increasing the current Caps, vessel and facility plan holders' current capability to implement *in situ* burn operations must be compared with the capability in 1993. As with mechanical recovery, there are three important topics that must be considered: technological capability, equipment availability, and equipment deployment and operation in generic spill locations (ocean, inland, Great Lakes, rivers and canals) around the country within the prescribed time limitations (Tiers I, II, and III). The overall applicability of *in situ* burning to the range of spills that might be encountered also should be considered. Although *in situ* burning may be effective in certain spill scenarios, the relative occurrence of those scenarios must be examined to understand the role *in situ* burning may play in improving spill response capability.

Assessing **technological capability** involves reviewing advances in systems and equipment design and configuration over the past 5 years to highlight significant improvements. Technology assessment focuses on fire-resistant containment booms, igniter systems, and technology for predicting emissions transport and monitoring emissions levels. The capability of burning emulsions and suppressing emissions also is addressed.

Assessing improved ***equipment availability*** involves a review of *in situ* burn equipment currently on the market (in terms of representative models and their intended applications) compared with those available 5 years ago. The fourth and sixth editions of the *World Catalog of Oil Spill Response Products* (Schulze, 1993, 1997) are the primary sources of this information. The immediate availability of response equipment also is assessed by reviewing nationwide equipment inventories of major *in situ* burn equipment items (fire-resistant booms and ignition systems). The improved availability of this equipment since 1993 and corresponding *in situ* burn removal capacity are examined by coastal region. Recent developments in emissions monitoring procedures (e.g., development of the SMART protocol [USCG *et al.*, 1998]) is reviewed, as well as improvements in plume trajectory prediction and monitoring technology.

Assessing ***equipment deployment and operation*** includes an examination of the amount and storage locations of major systems and equipment, and ability to move equipment from one location to another to provide an augmented *in situ* burn capacity within Tiers I, II, and III. Current RRT policy on *in situ* burning (specifically pre-authorization and expedited approval provisions) are reviewed. This includes an assessment of the state of *in situ* burning acceptance and preparedness as reflected in various ACPs, and extent to which *in situ* burning is being integrated into spill response exercises.

The final step in assessing the role and impact of *in situ* burning on spill response capability involves examining a number of spills that occurred in offshore and nearshore areas of the United States to determine when *in situ* burning could have been used, assuming that today's inventory of equipment, implementation policies, and training levels had been in place. This assessment provides insight on the relative contribution of *in situ* burning as an oil spill removal technique, and the weight that it should be assigned in adjusting the current Caps.

5.1 HISTORY OF *IN SITU* BURN USE

Beginning in the late 1970s and continuing through the 1980s, technology was developed and evaluated to provide the equipment and techniques for the safe, efficient use of *in situ* burning as an oil spill countermeasure. These efforts have produced various devices to support open-water burning of oil, including fire-resistant booms and ignition devices, which are part of the current spill response arsenal. Buist *et al.* (1994) describe in detail the technology developed to date, procedures currently used, and environmental issues considered. Various fact sheets developed by the National Response Team, Science, and Technology Committee (NRT, 1995a, b, c) provide a more general summary of *in situ* burn technology and current policy governing its use.

Since the TORREY CANYON spill in 1967, *in situ* burning has been employed as a response technique for various spills with varying degrees of success. Throughout the 1980s, it was considered as an alternative countermeasure to mechanical recovery, particularly in Arctic regions where the remoteness of potential spill scenes and presence of ice often would preclude mounting a successful mechanical recovery operation. It was not considered a "primary" countermeasure for spills in offshore and nearshore areas of the continental United States. This perception began to change in 1989, however, when fire-resistant booms were used in the initial stages of the EXXON VALDEZ spill response, during which 15,000 gals

of Prudhoe Bay crude oil were burned effectively (Allen, 1991). In a situation where all other spill response techniques appeared marginally effective, this modest accomplishment provided renewed interest in developing *in situ* burning as a countermeasure of choice for major open-water spills.

When the interim regulations governing vessel and facility response requirements were first published in 1993, *in situ* burning generally was regarded as an experimental albeit attractive technique. Accordingly, the current regulations (33 CFR 155 and 33 CFR 154) do not allow credit against on-water recovery capacity based on the availability of *in situ* burning as a high-rate response method, unlike the treatment of dispersants in 33 CFR 155 Appendix B and 33 CFR 154 Appendix C. Much has changed since 1993, however, with *in situ* burning and the policy for its use evolving steadily.

Research and technology development efforts have intensified in the years following EXXON VALDEZ to improve fire-resistant boom design, refine operational procedures, and resolve issues associated with air contamination from burning. These research efforts culminated in an international, multi-agency test burn in 1993 offshore of St. Johns, Newfoundland known as the Newfoundland Offshore Burn Experiment or NOBE (Fingas *et al*., 1995b). The experiment verified that *in situ* burn operations can be conducted safely and effectively, with burn efficiencies exceeding 90% (percentage of oil removed from the water surface); helped address many of the uncertainties regarding air contamination; and confirmed the overall viability of *in situ* burning as a legitimate response countermeasure. As a result, there is growing acceptance of *in situ* burning as a standard countermeasure, with RRTs and Area Committees integrating it into their response protocols and contingency plans. *In situ* burning is now considered a viable countermeasure for larger, offshore spills and certain inland, on-water spills in isolated locations. *In situ* burn scenarios are now being incorporated into oil spill response training exercises routinely.

Chapter 2 reviews the history of spills 1,000 gals or greater in the United States from 1993 to 1998. Criteria that roughly approximate existing pre-authorization indicate that 24% (56 of 231) of all spills in the data set (for the historical analysis in Chapter 2) that occurred in nearshore and offshore waters would have been candidates for *in situ* burning. If pre-authorizations were extended to within ¼ nmile from shore and 10 ft or more water depth, 39% (90 of 231) of all spills in the data set would have been candidates for *in situ* burning.

Kucklick and Aurand (1995) report similar findings. They review marine oil spills 1,000 bbls or more in the coastal and offshore waters of the United States (excluding Alaska) from January 1973 through June 1994. They identify 321 spills, but could obtain adequate date for only 207 of those spills (69 crude oil spills and 138 refined oil spills). Using the existing criteria described in Chapter 2 of this Caps review (roughly equivalent to existing pre-authorization zones), 11% (24 of 207) of all spills in Kucklick and Aurand's data set would have been candidates for *in situ* burning. Using the expanded criteria (spills greater than ¼ nmile from shore and 10 ft or more water depth), 20% (40 of 207) of all spills in Kucklick and Aurand's data set would have been *in situ* burn candidates. The authors conclude that restricting *in situ* burning use to offshore areas significantly limits the potential for use of this technology throughout the United States, except in the Gulf of Mexico (Region VI – Gulf Coast, 8th USCG District), which has the greatest number of spills.

Based on the data from Chapter 2 and Kucklick and Aurand (1995), if considering *in situ* burn use is limited to pre-authorization areas, then:

- Candidate spills 1,000 bbls or greater may occur approximately once per year.

- Candidate spills 1,000 gals or greater may occur approximately 3–4 times per year.

- The majority of all candidate spills will occur in the western Gulf of Mexico

- Candidate spills of 1,000 gals or greater will occur in every coastal region of the United States.

If considering *in situ* burn use is expanded to ¼ nmile from shore and 10 ft water depth, then:

- Candidate spills 1,000 bbls or greater may occur approximately 1–2 times per year.

- Candidate spills 1,000 gals or more may occur approximately 4–5 times per year.

- The majority of candidate spills will occur in the western Gulf of Mexico.

- Candidate spills will occur in every coastal region of the United States.

Although the current regulations for vessel and facility response plans do not address *in situ* burning directly, they do require that the USCG address "high-rate response techniques" as well as "other applicable response technologies" as part of this Caps review [as specified in 33 CFR 155.1050(p) and 33 CFR 154.1045(n)]. Given the credibility and acceptance that *in situ* burning has achieved since 1993, it is clearly appropriate that its impact on response capability be assessed in detail relative to the proposed Caps increases.

5.2 *IN SITU* BURN PROCESS

In conducting *in situ* burning, a number of steps must be followed and several issues addressed to ensure that the operation is both successful and safe. A schematic of the overall process is provided in Figure 5-1. The first step in the process is to locate, intercept, and concentrate oil to a thickness that will support *in situ* burning (generally 2 mm or more).

As with mechanical recovery, successful *in situ* burning depends on the ability to capture and concentrate oil quickly. The greatest volume of oil possible must be removed before it becomes unburnable because of weathering and slick dispersion. This generally requires oil tracking and mapping, which usually are accomplished through aerial surveillance using fixed-wing aircraft or helicopters. The current state of oil spill detection and tracking technology is described in some detail in Section 3.2. Visual surveillance can be used to detect and map larger concentrations of oil, and qualitatively determine where thicker portions of a slick are located during daylight hours and good visibility. Radar and UV/IR
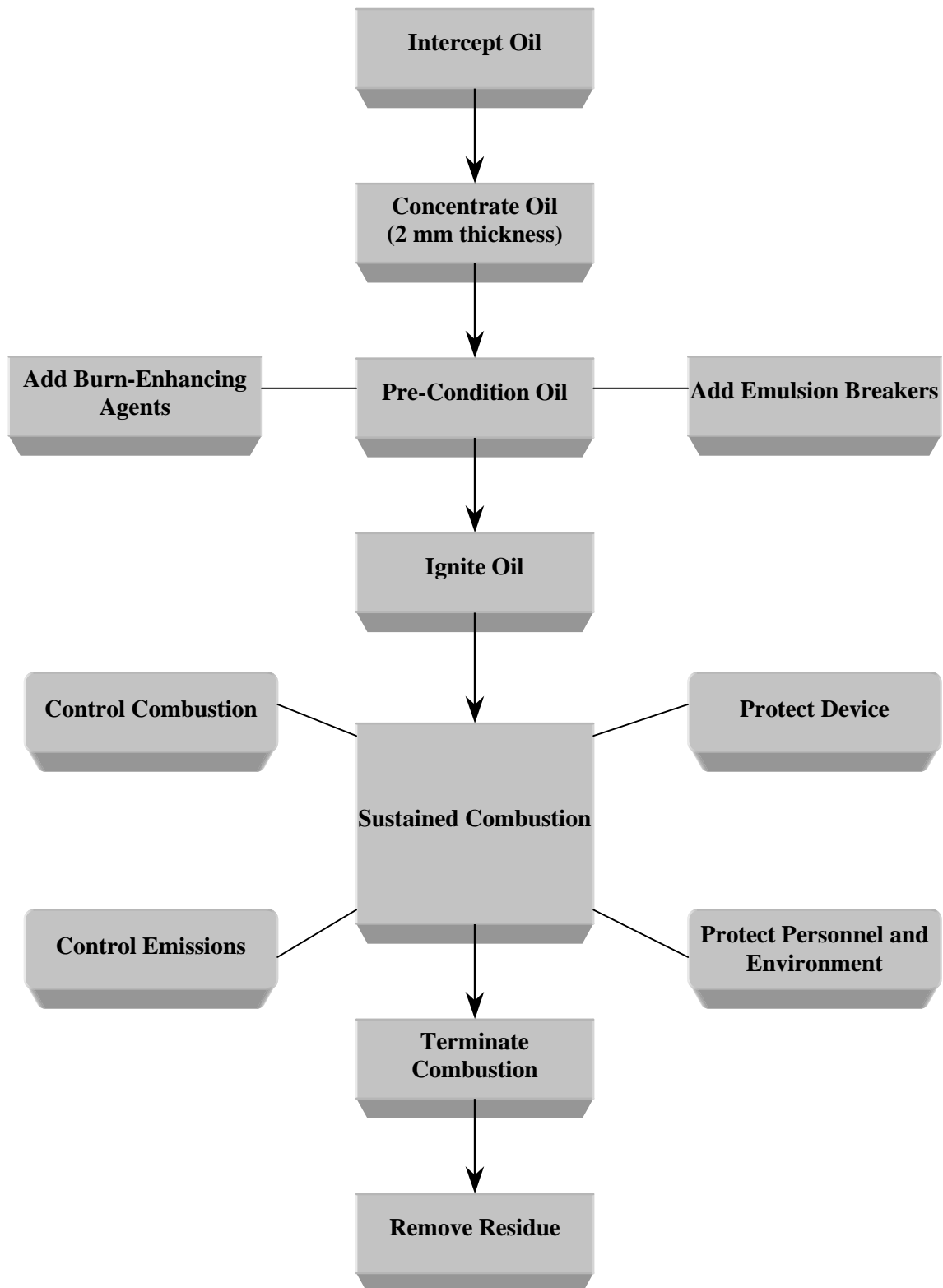
FIGURE 5-1. Schematic of the *In Situ* Burn Process Using a Containment and Combustion Device.

sensors are capable of determining slick location and extent in reduced visibility, although they often are limited by the presence of other substances and physical phenomena that can be mistaken for an oil slick. Portable, inexpensive IR sensors are now available that allow locating and mapping slicks at night and during periods of limited visibility. There is continued development of sensors that will identify oil positively (specifically laser fluorosensors); however, these devices are not yet integrated into readily available, operational oil spill reconnaissance systems. No currently available sensor directly measures slick thickness—the key parameter of interest for *in situ* burning. For *in situ* burning, the supporting detection and tracking technology remains unchanged since 33 CFR 155 and 33 CFR 154 were first published.

Oil must be concentrated to a thickness of 2 mm or more to burn successfully. Concentrating oil involves towing a fire-resistant boom through oil (such as in an offshore, open-water spill) or positioning boom in a current to intercept oil (such as downstream of an offshore platform blowout). The amount of oil encountered depends on the thickness of oil, amount of boom deployed and width of boom opening, and tow speed (or relative current) that can be maintained without oil entrainment beneath the boom. The ideal tow speed (or relative current velocity) when using fire-resistant boom is 0.75 kts or less. Sea conditions should be 2–3 ft or less. At tow speed and sea conditions above these values, oil will be transported (entrained) under the boom: at tow speeds above 1.5 kts and sea conditions above 4 ft, oil containment is completely ineffective.

After oil is concentrated, the next step is to ignite the oil so that the combustion process is self-sustaining. Assuming that wind and sea conditions are moderate, this can be accomplished with a handheld device or a more sophisticated ignition system such as the Helitorch (see Section 5.3.2). For larger spills requiring continuous burning over longer periods of time, a device capable of re-igniting the oil on demand (e.g., the Helitorch) probably will be required.

Once oil has been ignited, the goal is to maintain steady combustion at as high a burn rate as possible, while protecting equipment, spill response personnel, and the environment from undue harm. Heavily damaged fire-resistant booms will have to be replaced as required. After the combustion process is complete, burn residue should be recovered, if at all possible, using mechanical recovery equipment. Protecting personnel requires keeping them far enough from the burn to prevent flame radiation hazard and worker exposure to toxic emissions (that is, no personal protective equipment is required).

Protecting the environment includes ensuring that emissions do not pose a health risk to human populations and marine resources. Agencies such as the Centers for Disease Control and Prevention (CDC), EPA, NOAA, and National Institute of Standards and Technology (NIST) acknowledge that an acceptable safety buffer for marine *in situ* burning is 3 nmiles or more from a population center (offshore), or in isolated nearshore or inland areas. *In situ* burning pre-approval agreements in place around the country require emissions monitoring to protect public health and safety.

This chapter focuses on the technical feasibility of *in situ* burning as a response tool in the specific context of the Caps. Air emissions of *in situ* burning and associated health risks are

addressed briefly. Other agencies continue their close examination of air emissions, with their findings reflected in RRT policy directives on *in situ* burning.

The final consideration is the ability to terminate a burn in an emergency, such as would be caused by severe weather, damage to equipment, marine birds and mammals being sighted in the burn area, or by wind shifts that will carry the emissions plume toward populated areas. The current strategy for emergency termination of a burn is to increase tow speed such that oil entrains underneath the boom, or release one end of the boom so that oil escapes and spreads to a thickness less than 2 mm such that the fire is extinguished.

To determine the overall applicability of *in situ* burning as an oil removal option, it is important to consider the window of opportunity for using it effectively, and the nature of spills where it is most likely to be employed. Past research and experience (Buist *et al.*, 1994) indicate that oil can be burned when it is relatively un-weathered (subjected to moderate evaporation and emulsification), which generally makes *in situ* burning most effective in the first few days (~72 hours) of a spill. It is also difficult to burn heavier oils since lighter, more volatile components have been removed by the refining process. *In situ* burning is also more likely to be used on larger spills where the oil can be easily located and concentrated to the required 2-mm thickness, and where there is an immediate need to remove large quantities of oil from the surface to prevent shoreline contamination. While highly effective in some spill situations, *in situ* burning is not as universally applicable as mechanical recovery.

5.3 ASSESSMENT OF CURRENT TECHNOLOGY

5.3.1 Fire-Resistant Booms

The development of containment booms that allow for the collection of spilled oil and subsequent combustion began in the late 1970s, when it became apparent that mechanical recovery technology was far from adequate in handling large offshore spills. To capture and concentrate oil in a thickness that allows continuous burning (2 mm or more), standard oil containment boom designs were modified to be fire-resistant. Fire-resistant fabric covered the boom, and the internal structure was strengthened to withstand both heat and mechanical forces that would be encountered. "Fire-resistant" is generally used rather than "fireproof" because most fire-retardant materials undergo some degradation when subjected to the intense heat and flame associated with *in situ* burning for long periods of time. An alternative approach was constructing booms of a fireproof material such as stainless steel.

Several brands of fire-resistant boom are listed in the *World Catalog of Oil Spill Response Products* (Schulze, 1993, 1997; see also Tables/Figures B-1 and B-2 in Appendix B). A non-technical description of the technology is available in NRT (1995a), and Buist *et al.* (1994) provide a more complete description of this technology and its development. These booms represent a proven, commercial technology at a reasonable cost. They can be transported by air or ground easily, and deployed with a reasonable amount of effort.

Fire boom that is constructed of stainless steel is far more durable when exposed to heat and flame. Stainless-steel boom has been under development since the late 1970s. Dome

Petroleum, Ltd. constructed and tested a full-scale prototype both at OHMSETT (burn tests) and at sea (seakeeping tests without oil). These tests clearly showed the design's ability to withstand high temperatures for extended periods of time, contain oil in sea states of at least 2–3 and currents of 0.4 m/s (~ 0.75 kts), and survive without damage for long periods at sea (Buist *et al.*, 1983). The drawbacks for these booms are their size and weight (which complicate transport, deployment, and retrieval), and relatively high cost.

Although several versions of the stainless-steel boom have been produced and commercially marketed over the years (Buist *et al*., 1994), the only design listed in the sixth edition of the *World Catalog* is the Spill-Tain Boom (Schulze, 1997). The MMS, USCG, and Canadian Coast Guard commissioned an R&D effort by S.L. Ross, Ltd. to refine the original Dome Petroleum design, and make it easier to handle and less costly. The current configuration has half the weight and twice the buoyancy-to-weight (B/W) ratio as the original. The strategy for using such a boom would be to use it at the apex of the towed fire-resistant boom configuration, where temperatures and heat flux are most intense. The remainder of the boom configuration would be standard fire-resistant boom, with the stainless-steel portion referred to as the pocket boom. If successful, the pocket boom configuration will provide another alternative for handling longer-term burn operations, including those resulting from blowouts.

Another approach to extending the life of fire-resistant boom is to develop a water-cooled version—water is pumped through the boom continuously to prevent heat damage. American Marine, in collaboration with Mid Mountain Materials and Spiltec, Inc., is developing and testing a prototype. If successful, the water-cooled boom should allow continuous burning in a single boom for extended periods of time (up to several days*).* The pumps to supply cooling water are located on the tow vessel. The water-cooled boom would provide a reasonable approach for handling larger offshore and continuous-source spills where burn operations of one to several days are expected.

Allen and Ferek (1993) describe equipment and practice in using fire-resistant boom during an *in situ* burn: 300 to 500 ft (92 to 152 m) of fire boom; two boom-towing vessels with twin propellers, tow posts, and tow lines at least 500 ft (152 m) long; and a means of ignition. The two boom-towing vessels would pull the fire boom in a U-configuration at approximately 0.75 kt or less to intercept and hold oil in the downstream apex of the boom.

This approach to *in situ* burning has been employed during several at-sea test burns, as well as during the EXXON VALDEZ spill. In July 1988, an at-sea test burn was conducted off Spitzbergen, Norway with approximately 500 gals of Statfjord crude oil contained in 300 ft of 3M Fire Boom (Allen, 1993). This test served as a prelude to the first application of the technology in a major accidental spill. During the EXXON VALDEZ burn, 450 ft of 3M Fire Boom were towed by two vessels at a speed of approximately 0.75 kt (0.4 m/s) to collect the oil. After 30 minutes of oil collection, the oil was ignited. Allen (1991) estimates that the amount of oil burned was 15,000–30,000 gals in approximately 45 minutes. The residue was approximately 300 gals, or 2% of 15,000 gals.

The 3M Fire Boom used in the short-duration burn performed well with only minor degradation. Following the burn, inspection of the 3M Fire Boom revealed an expected

amount of thermal stress to certain boom components, resulting in a slight loss of freeboard[1] and some fabric embrittlement between flotation segments. The boom was in satisfactory condition to be used for additional oil collection and burn operations.

The success encountered at EXXON VALDEZ using *in situ* burning, compared with the relative inefficiency of other cleanup technologies, prompted a renewed interest in the technique, and additional research and testing followed. These efforts culminated in the NOBE burn, a major at-sea, *in situ* burn test. In the NOBE burn, the boom was 700 ft long and consisted of some commercial sections and some experimental sections. The boom was towed at a speed of approximately 0.5 kts. Two experimental burns were conducted during the deployment (Environment Canada, 1997).

For the first burn, 12,760 gals of oil were pumped into the boomed area and ignited. Inspection of the boom after the burn revealed some signs of abrasion in the Nextel ceramic fabric above the waterline between flotation logs. At these locations, some small gaps in the fabric appeared approximately 10–20 cm from the vertical stainless-steel stiffeners. Nevertheless, the boom was fit for another burn (Fingas *et al*., 1995b).

For the second burn, 7,635 gals of oil were discharged into the boom. Pumping and burning took 80 minutes; at that point, some pieces of the boom were lost. In a prototype section (that included some external tension members near the waterline), the stainless-steel wire mesh had parted, allowing two meter-long flotation logs to be released. After the test, analysis of the crystalline structure of the wire mesh revealed embrittlement at the location where the flotation logs had been released. Anecdotal accounts from the crew that recovered the burned boom sections after the experiment suggest that damage to the floats, mesh, and refractory fabric of the NOBE boom was severe (Environment Canada, 1997). The results of the NOBE burn clearly indicate that the fire-resistant booms available at the time of the experiment would suffer progressive deterioration when subjected to the heat and mechanical stresses of at-sea burning.

As a result of this apparent limitation in boom durability, several U.S. and Canadian agencies—MMS, USCG, Texas General Land Office (TGLO), and Environment Canada—MSRC, and several boom manufacturers have undertaken additional testing efforts to better define boom performance, and establish a standard protocol for fire-resistant boom tests. In 1995, additional at-sea tests were conducted to determine the durability and seakeeping characteristics of several commercially available boom designs. MSRC, TGLO, and MMS tested the at-sea towing capabilities of four booms:

- Applied Fabric Pyroboom
- Oil Stop Auto Boom Fire Model
- TGLO's SeaCurtain FireGard Oil Containment Boom
- The Navy 3M Fire Boom

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[1] Freeboard is the measurement of the height of the boom that extends above the water surface.

Sloan *et al*. (1995) describe the tests conducted in two phases. The Navy 3M Fire Boom was tested in the first phase at OHMSETT in New Jersey, and the other three booms were tested in the second phase at sea in Texas.

Performance data were obtained at tow speeds of 0.5, 1.0, and 1.5 kts and speed at boom submergence or skirt surfacing. Freeboard, skirt draft, tow force, and speed at submergence were measured for each boom. Tests, which were conducted in sea state 1, showed that boom freeboard decreased with increasing tow speed for all booms tested. None of the booms, however, met the American Society for Testing and Materials (ASTM) static freeboard (calm-water design freeboard) requirement for open water, which is 53 cm (21 in). Rather, most of the booms only met the recommended freeboard for protected water, which is 26 cm (10 in) (Sloan *et al*., 1995).

Skirts, employed to prevent oil from passing under the boom, maintained relatively constant depths. Rather than remaining vertical, the skirts angled into or out of the apex of the boom as tow speeds increased. Again, the boom had difficulty meeting the ASTM standard for open-water containment boom. Sloan *et al.* (1995) also investigate the tow speed at which the apex of the boom becomes submerged. They show an exponential relationship between B/W ratio and tow speed at submergence.

All booms suffered damage, with deployment and retrieval operations contributing to most of the damage. Fire-resistant material was susceptible to tearing. In particular, the Navy 3M Fire Boom was scraped and scratched during launch, later leading to the design of a launching container. As Sloan *et al.* (1995) emphasize, booms should be able to withstand normal handling conditions. The Navy 3M Fire Boom also experienced connector failure at the apex of the boom after being towed at 1.5 kts for 10 minutes (Sloan *et al*., 1995). In all, the at-sea towing tests showed that current fire-resistant booms do not meet the seakeeping performance characteristics for open-water boom, and will be effective in sea states of 3 or less.

At-sea boom fire-resistance testing that involves oil release and burning is expensive and difficult to arrange. To overcome these problems, NIST researchers designed several techniques to test boom in tanks that allow exposure to heat, flame, and mechanical stress because of wave action in controlled settings. These tests were conducted in test tanks located at the USCG Marine Fire and Safety Test Detachment in Mobile, Alabama and the Canadian Hydraulic Centre in Ottawa, Ontario. Tests were conducted using diesel oil and propane as a fuel under various simulated wave conditions. Walton (1998) summarizes these test procedures.

The test procedures conform to a draft standard test guideline developed by the ASTM F-20 Committee entitled *Standard Guide for* In Situ *Burning of Oil Spills on Water: Fire-Resistant Boom* (*Unpublished draft under consideration*, ASTM, Philadelphia, PA). The draft standard currently is considered a guideline since it provides only general performance requirements and does not specify a detailed evaluation procedure. The draft standard calls for boom tests using a burn exposure-cool down cycle sequence consisting of 1 hour of burning, followed by 1 hour with no burning, 1 hour of burning, 1 hour with no burning, and finally 1 hour of burning. The booms are subjected to wave action throughout the test. The

standard guide also specifies wave characteristics, and burn intensity (temperature and heat flux). Despite its draft status, the standard guide is a significant step forward in encouraging and documenting fire-resistant boom development and performance.

Tests using this standard guide were conducted in Canada in 1996 and 1997, with propane as the fuel. McCourt *et al*. (1997, 1998) report the test results. Similar tests were conducted at the USCG Marine Fire and Safety Test Detachment using diesel fuel in 1997 and 1998. Five boom designs were tested in 1997; six boom designs were tested in 1998. These boom designs represented the majority of booms currently available for use. Walton (1998) reports the results of the 1997 test series. The report on the 1998 tests is not yet available.

To date, tests have shown that *in situ* burn parameters at sea can be simulated in a test tank environment successfully. As expected, all booms, with the exception of the stainless-steel boom, showed signs of progressive deterioration with subsequent fire exposure, thus indicating a limited service life. Further tank tests using propane were conducted at OHMSETT. More recent tests at the USCG Marine Fire and Safety Test Detachment and OHMSETT have included the improved stainless-steel pocket boom and water-cooled Hydro-Fire Boom developed by Elastec/American Marine. These designs showed negligible deterioration when subjected to the *in situ* burn test procedure (*Personal communication*, A. Allen of Spiltec, Inc., Woodinville, Washington and I. Buist of S.L. Ross, Ltd., Ottawa, Ontario).

In summary, the performance of fire-resistant fabric booms is improving steadily, although these booms are not as seaworthy as standard open-water containment booms. These booms also can be expected to deteriorate over time when subjected to continuous burning or numerous successive burn cycles. A conservative estimate of their service life in actual burn operations is ~6–10 hours. Several boom designs are currently available for use. Advanced boom designs, such as the stainless-steel pocket boom and water-cooled boom, may permit extended burn operations (one to several days), but as of 1998, these were still under development. If current development and testing efforts are successful, however, these advanced designs could be available for operational use within the next 1–2 years.

5.3.2 Ignition Devices, Systems, and Techniques

Buist *et al.* (1994) detail and NRT (1995b) summarizes a number of compounds, devices, and systems that have been investigated and tested for igniting oil slicks at sea. Investigated compounds include sodium and gasoline, hypergols, solid fuels (e.g., gelled kerosene or gasoline), solid propellants (rocket fuels), sodium and gasoline, and proprietary chemical mixtures such as Westcom 2000. All of these compounds are effective in igniting oil; the major constraint for their use is the difficulty in keeping them at the oil/water interface, and in some cases, the need for a secondary igniter. These compounds also are inherently highly flammable and/or explosive, thus requiring extreme caution in handling, transport, and storage.

Various hand-deployed devices have been used for oil slick ignition, including incendiary devices such as marker flares and thermite grenades, as well as devices specifically designed for igniting oil slicks (e.g., the Canadian EPS or "Pyroid" igniter, and the Dome Petroleum/

Energetex igniter). These devices are constructed to float at the oil/water interface. Being armed only at deployment, they are safe for transport and storage aboard aircraft and vessels, but must be stored in a spark free, dry area away from heat sources and other flammable material. Both igniters were produced commercially but are no longer available for immediate procurement and use. A more recently developed handheld igniter developed by Spiltec, Inc. consists of a nalgene bottle filled with gelled gasoline and a distress flare mounted in a styrofoam float. Such a device has been tested successfully (Guénette and Thornborough, 1997) and can be constructed on-scene easily.

The current system of choice for igniting oil during *in situ* burn operations, particularly for large spills where several fire-resistant boom are deployed, is the Helitorch system, commonly used for setting backfires in controlling forest fires. Helitorch is a completely self-contained system consisting of a fuel barrel (filled with gelled gasoline or a gasoline and diesel mix) and pump and motor assembly mounted on a support frame. The gelled fuel mixture is ignited by an electric filament and propane jet ignition system. The burning fuel is delivered in a highly viscous stream that breaks into burning globules before hitting the surface. The system, which is slung from a helicopter (hence the name Helitorch) during operation, is flown at a speed of 40–50 km/hr, at an altitude of 8–23 m. This provides for an even distribution of the burning fuel over a wide area. Recent tests during an *in situ* burn demonstration in the United Kingdom have confirmed the utility of the Helitorch for igniting oil during *in situ* burn operations (Guénette and Thornborough, 1997). These tests also demonstrated the feasibility of incorporating an emulsion breaker into the napalm mixture to allow ignition of emulsified oils.

Of the systems described above, the Helitorch is preferred for extended offshore *in situ* burn operations. For the expedited ignition of spills contained in fire-resistant boom, simple floating igniters can be allowed to drift into the oil (e.g., a plastic bag with gelled fuel, kerosene/diesel-soaked piece of sorbent, or Spiltec igniter). *In summary*, ignition of an oil slick is a straightforward procedure with devices and systems already developed and available.

5.3.3 Additives for Enhanced Burn Efficiency and Emissions Control

A number of chemical additives have been proposed to improve burn rate, allow burning of oil/water emulsions, and decrease the level of visible emissions (smoke) that is often considered a primary drawback to *in situ* burning. Buist *et al.* (1994) discuss the technology in detail. Viewed in isolation on a small scale, each of these additives has proved generally effective. The primary operational drawbacks are the cost and logistics in delivering and distributing the additive over contained oil (as with *in situ* burning in a fire-resistant boom). Use of these chemical additives is subject to pre-approval and/or incident-specific approval in accordance with the National Contingency Plan. None of the current *in situ* pre-authorization agreements in place around the country authorizes the use of any additives.

A number of additives have been developed to promote burn efficiency. Burn promoters generally serve as insulators and wicking agents to enhance oil burning. They include powder products (e.g., Cab-OSil, Aerosil, and Tullonox), fiber and granular substances (e.g., Fibreperl, Ekoperl, Wonderperl, Vermiculite, and Peat Moss), and cellular glass beads

(commercially marketed as Seabeads). Each substance is spread throughout an oil slick at the oil/water interface, and each has been shown to enhance burning to some extent.

Emulsion breakers also can be used to promote combustion by reducing the oil's water content to less than 50% water, which allows ignition and enhanced burning. The primary difficulty in using such substances for *in situ* burning is the high dosage rate and complicated logistics in distributing the additive over a wide area of the spill. In laboratory tests, adding emulsion breakers to oil before ignition was the most effective means to enhance ignition, particularly for highly stable emulsions. In field tests, using an emulsion breaker with gelled oil has proven to be an effective means of igniting otherwise unignitable emulsions with the existing igniter technology (i.e., Helitorch and gelled gasoline), as Guénette *et al.* (1994) report: not all emulsion breakers have the same effect or impact on the ignition of emulsions, and emulsion breakers appear to be oil specific to a certain extent. More recent field tests using a Helitorch-Deployable Emulsion Breaking Igniter EBI (Guénette and Thornborough, 1997) showed the effectiveness under actual spill conditions to ignite oil contained in a fire-resistant boom.

A number of organometallic compounds have been investigated as smoke-suppression agents. The most successful of these has been ferrocene, which, as a crystalline solid, is insoluble in water, slightly soluble in oil, and non-toxic. Tests of ferrocene applied to oil as a smoke suppressant have shown that a 90–95% reduction in soot is possible by adding as little as 2% of ferrocene compound by weight (Mitchell, 1990; Mitchell and Janssen, 1991). Moir *et al.* (1993) report that the latest ferrocene hybrid, RMS 9757, reduces soot up to 70% with addition of 0.5% of additive by weight. Although the dosage rates for ferrocene are reasonable, application in open burning at sea is still limited by the logistics of transporting large quantities of the additive to a spill scene and distributing it evenly over a slick. In addition, ferrocene must be mixed in another compound so that it does not sink. Cost is another limiting factor (approximately $400/lb for the pure substance).

Compressed air is another recently investigated, straightforward, burn-enhancing, smoke-suppressing additive. Tests conducted by MSRC (Nordvik *et al.*, 1995b) examined the effect of compressed air supplied from both surface jets and a submerged bubbler system on oil burning in a contained area. The air jets above the surface clearly reduced the amount of smoke (based on qualitative observations) but were sensitive to ambient wind. The bubbler system appeared to be somewhat less effective in reducing smoke but was not impacted by the wind. Neither of these burn-enhancing techniques is directly applicable for *in situ* burning within a fire-resistant boom at sea.

In summary, a number of additives have been investigated to enhance oil ignition, promote burn efficiency, and reduce visible emissions. For open burning with a fire-resistant boom, using an emulsion breaker mixed with a gelled-gasoline igniter appears operationally feasible. Treating the entire oil slick within the fire-resistant boom with emulsion breakers is not operationally feasible, and requires further research on the proper formulations and dosage rates for specific oils, as well as development of distribution techniques. The use of additives such as ferrocene to suppress visible emissions, or the use of aeration techniques to improve burn efficiency, also is not operationally feasible at this time.

5.3.4 Technologies and Procedures for Predicting Plume Trajectories and Monitoring Emissions

Scientific understanding of the composition and potential environmental hazards of *in situ* burn emissions has increased significantly since 1993. Ferek *et al.* (1997) provide a summary of the current knowledge of air quality considerations for *in situ* burning. Because of this increased understanding, procedures and technologies to predict plume trajectories and monitor emission levels downwind of a burn also have improved dramatically.

A major objective of the meso-scale burn tests at the USCG Marine Fire and Safety Test Detachment (1993–1997) and the 1993 NOBE test series was to meticulously analyze the emissions from *in situ* burning so that the potential threat to the environment and downwind human populations could be clarified. These tests, as summarized in various papers and data reports (Environment Canada, 1997; Fingas *et al.*, 1995b) clearly showed that emissions generated by a typical *in situ* burn operation at sea (in terms of soot particles and hazardous gases) are unlikely to pose health risks since no significant levels of smoke particles were detected at the surface even 25 nmiles away.

The emission component of greatest human health concern is the PM-10 level—the concentration of soot particles of 10 μ in diameter and less, expressed in μ/m^3. These particles are composed of small pieces of elemental carbon and hydrocarbons that are small enough to remain suspended in air and can be inhaled. The conservative limit for human exposure to PM-10 particles currently is set at 150 μ/m^3 averaged over a 1-hour period per NRT guidelines (NRT, 1995c).

In the NOBE tests, PM-10 concentrations did not exceed 150 μ/m^3 when sampled immediately next to the fire and as far out as 25 nmiles downwind. Total smoke particles emitted from the NOBE burn were equivalent to those emitted from burning 9 acres of forest land. Analysis of the gaseous emissions from the NOBE tests indicated that concentrations of carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide, and volatile organic compounds are of little concern outside the immediate burn vicinity. It should be noted, however, that different wind and atmospheric stability may lead to elevated PM-10 levels downwind of the burn such that burning may be precluded.

Based on this knowledge, the NRT has promulgated specific recommendations for *in situ* burning regarding acceptable distances for general populations downwind of the burn, PM-10 levels of concern for general populations, appropriate monitoring strategies, and safety and health guidance for responders. These recommendations, along with future research priorities, are contained in *Guidance on Burning Spilled Oil* In Situ (NRT, 1995c).

Specific procedures for implementing these recommendations during *in situ* burn operations have been developed by the USCG and NOAA. In 1994, the two agencies developed SROMP to provide decision support information to the Unified Command during *in situ* burn operations (Barnea *et al.*, 1998). This monitoring protocol was tested during several land burns, as well as a series of meso-scale test burns in the USCG Marine Fire and Safety Detachment. Based on lessons learned, the SROMP protocol was reviewed, modified, and improved, and subsequently has been renamed the SMART protocol (USCG *et al.*, 1998).

The SMART protocol is under review by the NRT. SMART recommends three monitoring teams deployed at selected locations downwind of the burn to provide data on PM-10 levels to the Monitoring Group Supervisor within the ICS. Under both the SROMP and SMART protocols, USCG Strike Teams are assigned the monitoring task.

The technology for predicting and monitoring smoke plumes also has advanced significantly. As part of the overall *in situ* burn technology development effort, NIST researchers have developed A Large Outdoor Fire Plume Trajectory model (ALOFT), which is being used to predict and analyze the downwind distribution of smoke particulate and combustion products from large burns. The model is more capable than the various Gaussian models available in that ALOFT solves the fundamental fluid dynamic equations for the smoke plume in its surroundings using inputs such as wind speed and variability, atmospheric stability, number of fires, fuel parameters, and other emissions parameters. A Windows-based version of the model for flat terrain is available in the public domain (McGratten, 1998).

For monitoring PM-10 concentrations on the ground, real-time particulate monitoring devices (such as the DataRam System) have been developed and tested in conjunction with the various *in situ* burn experiments conducted over the past several years. These instruments provide instantaneous readings of particulate concentrations, as well as a time-weighted average over the period that the instrument has been logging data. This allows monitoring teams to quickly determine if the NRT PM-10 guidelines (150 μ/m^3 averaged over a 1-hour period) are likely to be exceeded. Positioning data for the teams is provided by a portable GPS receiver.

In summary, the technology to effectively predict smoke plume trajectories and monitor particulate concentrations has evolved with the *in situ* burn research program over the past few years. Monitoring protocols have been established and promulgated based on the scientific findings of burn experiments. This monitoring capability can be readily employed to support an *in situ* burn operation.

5.4 *IN SITU* BURN RESOURCE AVAILABILITY

5.4.1 Fire-Resistant Boom Availability

A number of fire-resistant boom designs have been developed, tested, and marketed over the years. The sixth edition of the *World Catalog of Oil Spill Response Products* lists several designs that are commercially available (Schulze, 1997; see also Tables/Figures B-1 and B-2 in Appendix B). Table 5-1 provides a summary of booms available in 1993 (as listed in Schulze, 1993) as compared to those available in 1997 (as listed in Schulze, 1997).

It is clear from Table 5-1 that the number of booms on the market, and the level of boom-performance testing undertaken, has increased significantly in the past few years. This may be attributed to the renewed interest in *in situ* burning and the government-sponsored fire-resistant boom testing program described in Section 5.3.1.

TABLE 5-1. Fire Containment Booms Available in 1993 and 1997.

	MANUFACTURER	MODEL	DIMENSIONS			COST	TESTED/USED
			FREEBOARD (IN)	DRAFT (IN)	STANDARD LENGTH (FT)		
1993	3M Company	8 in	6	15	50	$170/ft	EXXON VALDEZ
		12 in	9	21	50	$200/ft	
		18 in	15	28	50	$270/ft	
	Kepner Plastics Fabricators, Inc.	FireGard 812FG	6	14	100	Inquire	Manufacturer tests
		FireGard 1115FG	8	18	100	Inquire	
		FireGard 1418FG	11	22	100	Inquire	
		FireGard 1823FG	15	26	100	Inquire	
1997	3M Company	8 in	6	15	50	$170/ft	EXXON VALDEZ MSRC At Sea, 1994 USCG Mobile, 1997
		12 in	9	21	50	$200/ft	
		18 in	15	28	50	$270/ft	
	Spill-Tain Div., M.C.D. Company	23 in	11	11	7.5	Inquire	OHMSETT, 1981,1996 Manufacturer Tank Tests, 1982, 1995
		35 in	17	17	11.5	Inquire	
		47 in	23	23	15	Inquire	
	American Marine, Inc.	20 in	6	15	50	Inquire	Spitzbergen, 1988 EXXON VALDEZ NOBE Tests, 1993 OSRL North Sea, 1996 OHMSETT, 1996, 1997
		30 in	9	21	50	Inquire	
		42 in	15	27	50	Inquire	

	Kepner Plastics Fabricators, Inc.	FireGard 812FG	6	14	100	Inquire	Manufacturer Tests
		FireGard 1115FG	8	18	100	Inquire	OHMSETT, 1996
		FireGard 1418FG	11	22	100	Inquire	
		FireGard 1823FG	15	26	100	Inquire	
	Applied Fabric Technologies, Inc.	PyroBoom	14	16	105	Inquire	OHMSETT, 1996
	Oil Stop, Inc.	Offshore Auto Boom, Fire Model	15	25	50	Inquire	Manufacturer Test, 1994, OHMSETT, 1996

Note: MSRC, Marine Spill Response Corporation; USCG, U.S. Coast Guard; OHMSETT, Oil and Hazardous Material Simulated Environment Test Tank; NOBE, Newfoundland Offshore Burn Experiment; OSRL, Oil Spill Response Limited.

Source: Adapted from personal communication with various suppliers and Schulze (1993, 1997).

Since 1992, the amount of fire-resistant booms pre-staged around the country has increased steadily as *in situ* burning has gained acceptance as an oil spill countermeasure. Table 5-2 summarizes the inventory of fire-resistant booms that is available from oil spill removal organizations (OSROs) in the United States.

The readily available supply of fire-resistant booms has increased dramatically since 1993. Prior to 1993, only a few sections of fire-resistant booms were available in Alaska, and there were virtually no fire-resistant booms pre-staged in the continental United States.

5.4.2 Ignition System Availability

There are a number of Helitorch ignition systems available throughout the country. The most widely used Helitorch is manufactured by Simplex, and federal and state governments (Forest Service), helicopter companies, and OSROs own a number of these systems. Table 5-3 provides a summary of Helitorch ignition systems located in the United States.

TABLE 5-2. Location of Fire-Resistant Booms in the United States.

ORGANIZATION	LOCATION	INVENTORY OF FIRE-RESISTANT BOOMS
Alaska Clean Seas	Prudhoe Bay, AK	17,500 ft 3M Fire Boom
		2,082 ft old Shell Fire Boom
Alyeska (SERVS)	Valdez, AK	3,600 ft 3M Fire Boom
CCC	Fort Lauderdale, FL	750 ft 3M Fire Boom
		900 ft Oil Stop Fire Boom
CISPRI	Kenai, AK	6,150 ft 3M fire Boom
		1,000 ft Kepner Fire Boom
MSRC	Edison, NJ	500 ft Oil Stop Fire Boom
	Wilmington, DL	500 ft Oil Stop Fire Boom
	Miami, FL	500 ft Oil Stop Fire Boom
	St. Croix, USVI	500 ft Oil Stop Fire Boom
	Pascagoula, MS	500 ft Oil Stop Fire Boom
	Houston/Galveston, TX	500 ft Oil Stop Fire Boom
	Everett, WA	500 ft Oil Stop Fire Boom
	Honolulu, HI	500 ft Oil Stop Fire Boom

Note: CCC, Clean Caribbean Cooperative; CISPRI, Cook Inlet Spill Prevention & Response, Inc.; MSRC, Marine Spill Response Corporation.

Source: Personal communication with various suppliers.

TABLE 5-3. Location of Helitorch Ignition Systems in the United States.

SYSTEM	LOCATION	OWNER
2 Simplex	Fort Lauderdale, FL	CCC
3 Owner-Designed	Brewton, AL	Helicopter company
2 90 gals	Junction City, OR	Helicopter company
3 Simplex 55 gals	Eugene, OR	Helicopter company
6 Simplex & Western	Newberg, OR	Helicopter company
3 Simplex	Merlin, OR	Helicopter company
2 Simplex	Hillsborough, OR	Helicopter company
2 Simple 55 gals	Seattle, WA	Helicopter company
2 Simplex 55 gals	Darrington, WA	Helicopter company
2 Simplex	Nikiski, AK	CISPRI
8 Simplex	Prudhoe Bay, AK	Alaska Clean Seas
2 Simplex	Valdez, AK	Alyeska (SERVS)

Note: CCC, Clean Caribbean Cooperative; CISPRI, Cook Inlet Spill Prevention & Response, Inc.
Source: Personal communication with various suppliers.

In addition to Helitorch systems, there are several stockpiles of handheld igniters available, with Alaska Clean Seas in Anchorage having the largest supply (1,400 igniters). Much smaller inventories of handheld igniters are located at Clean Caribbean Cooperative (CCC) (12 igniters) and at MSRC pre-staging areas. Handheld ignition devices are constructed easily on-scene. Helitorch systems are preferred for extensive on-going *in situ* burn operations as they can ignite oil captured in a number of fire-resistant booms, and re-ignite oil in a boom if necessary.

5.5 ESTIMATE OF *IN SITU* BURN REMOVAL CAPABILITY BY REGION

In assessing the overall availability of *in situ* burn resources for an oil spill response in the United States, it is useful to examine the overall distribution of equipment by coastal region (as described in the note to Table 5-4), where coastal environments and climatic conditions are similar. Hawaii and the U.S. Caribbean represent special cases because of their distance from the continental United States.

Given these regional designations, and knowing the amount of fire-resistant booms and igniters available in each region, it is possible to derive a rough estimate of the overall oil removal capability represented by these resources. It is also possible to make a somewhat subjective determination of the ability to transport resources from one region to an adjacent or distant region within various time limits. The ability to augment *in situ* burn removal capacities within a region at the Tiers I, II, and III can then be estimated.

TABLE 5-4. *In Situ* Burn Removal Capacity for U.S. Coastal Regions*.

REGION*	BOOM LENGTH (FT) /500-FT SECTIONS	HELITORCH SYSTEMS	REMOVAL CAPACITY (BPD)
I – New England	0/0	0	0
II – Northeast	500 / 1	0	5,000
III – Middle Atlantic	500 / 1	8	5,000
IV – Southeast	2150 / 4	5	20,000
IV –U.S. Caribbean	500/1	3	5,000
VI – Gulf Coast	1000/2	0	10,000
IX – California	0 / 0	18	0
X – Pacific Northwest	500 / 1	24	5,000
Alaska	30,000 / 60	12	300,000
Oceania	500 / 1	0	5,000

Note: bpd, barrels per day

* Federal (EPA) regions are defined as follows: I – New England (Connecticut, Rhode Island, Massachusetts, New Hampshire, Vermont, Maine), II – Northeast (New York, New Jersey), III – Middle Atlantic (Delaware, Maryland, Virginia), IV – Southeast (North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi), IV – U.S. Caribbean (Puerto Rico, U.S. Virgin Islands), VI – Gulf Coast (Louisiana, Texas), IX – California, X – Pacific Northwest (Oregon, Washington), Alaska, and Oceania (Hawaii, Guam).

Estimating *in situ* burn capacity, as represented by a given length of fire-resistant boom, requires some fundamental assumptions. The first of these is that oil can be located and concentrated at a rate that allows efficient burning. The most variable parameter that determines the amount of oil available for burning is the thickness of the oil slick encountered. Near the source of a large spill, slick thickness of 10 mm or more may be encountered, but this will decrease rapidly as oil spreads to thicknesses ranging from between 0.1 mm (seen as a dark brown or black slick from the air) to 0.001 mm (seen as a silvery sheen). For the purposes of estimating removal capacity, a slick thickness of 0.1 mm to 1.0 mm will be assumed since this is the thickness at which slicks can be visually spotted and tracked from the air.

An estimate of oil volume available for burning in a fire-resistant boom can be made by choosing the length of boom that would be used (in this case 500 ft with the assumption that it is towed in a standard U-configuration), assuming a gap width (150 ft or 300 ft), choosing an oil thickness (0.1 mm or 1.0 mm), and calculating ORR using the formula below:

$$\text{ORR} = \text{relative speed of boom} \times \text{gap width of boom} \times \text{oil thickness}$$

This formula represents the volume of oil swept up by a boom with a given gap width as it is towed through a slick of uniform oil thickness at a specified speed. Using selected values of relative speed, gap width, and oil thickness, and making the necessary units conversions, the volume of oil that can be captured with a fire-resistant boom (expressed in barrels per hour, bph) is calculated in Table 5-5.

TABLE 5-5. Typical ORR Values for a 500-ft Section of Fire-Resistant Boom.

OIL THICKNESS	RELATIVE SPEED	ORR FOR GAP WIDTH OF 150 FT (BPH)	ORR FOR GAP WIDTH OF 300 FT (BPH)
0.1 mm	0.5 kts	26.6	53.2
0.1 mm	0.75 kts	39.8	79.6
0.1 mm	1.0 kts	53.2	106.4
1.0 mm	0.5 kts	266.6	532.0
1.0 mm	0.75 kts	398.5	797
1.0 mm	1.0 kts	532.1	1,064.2

Note: ORR, oil recovery rate; bph, barrels per hour; kts, knots.

By using various values and nomograms developed over the years, the amount of oil that can be burned once it is collected in the boom can be estimated. The burn area must be estimated for the length of boom being used. For a 500-ft length of fire-resistant boom, this burn area will range from roughly 7,000–17,000 sq ft, depending on the amount of oil in the boom at the time of ignition (Exxon, 1992). Given this burn area, the total removal capacity can be estimated using the burn rate, which ranges from 2.94 bpd/sq ft for crude oil to 3.36 bpd/sq ft for refined products. Making the conservative assumption that crude oil is involved, and that the burn area is 10,000 sq ft, it is estimated that a 500-ft section of boom, with a continuous supply of oil, is capable of burning approximately 30,000 bpd (or 1,250 bph assuming that the burn is continuous for 24 hours).

This value must be adjusted based on the assumption that burning will not be continuous but will proceed in several oil collection and burn cycles. It also is unlikely that burning will continue at night. Finally, it must be recognized that current fire-resistant boom designs probably will allow three to four 1-hour burn cycles before the boom must be repaired (i.e., sections in the boom apex replaced). Assuming that each 1-hour burn cycle is preceded by a 2-hour oil collection cycle means that the daily operation occurs over 9–15 hours (6–10 hours of collection time and 3–5 hours of burn time), spanning daylight hours. If the supply of oil is not limited, the amount of oil that can be removed in a typical day of *in situ* burning probably is between 3,750 and 6,250 bpd. A typical value for the removal rate per 500 ft of fire-resistant boom section would thus be 5,000 bpd, as proposed by Allen (1994).

Table 5-5 can be consulted to determine if the 5,000 bpd burn rate can be sustained by the rate of oil captured in the boom. It is reasonable to assume that a 500-ft section of boom will provide a 150-ft gap width and be towed at 0.75 kts without losing oil. (These are standard assumptions in the *Exxon Oil Spill Response Field Manual* [Exxon, 1992]). It is also reasonable to assume that *in situ* burn operations will be used for larger spills and focus on the thicker portions an oil slick such that a 1-mm uniform thickness is encountered. This provides an ORR of ~400 bph for a 500-ft section of boom. Assuming that oil collection time is 6–10 hours produces a daily ORR of 2,400–4,000 bpd. Based on these assumptions, this value is a conservative estimate of the oil that can be collected and burned with a 500-ft section of fire-resistant boom in a given day.

If the gap width of a boom can be augmented with conventional boom at the leading ends, and even thicker portions of the slick targeted, it seems reasonable that the 5,000-bpd removal rate can be achieved. Using this higher removal estimate also is consistent with the optimistic approach used to calculate mechanical recovery removal capacity, which completely ignores encounter rate and assumes that removal rate is solely a function of skimmer recovery capacity. Accordingly, for this analysis, the removal capacity of 5,000 bpd per 500-ft section of fire-resistant boom is used.

Using this figure, and considering the number of 500-ft fire-resistant boom sections in a given region, *in situ* burn removal capacity immediately available within each U.S. coastal region can be estimated. A summary of the amount of boom and Helitorch systems available, and immediate *in situ* burn removal capacity represented by these resources for each region (based on the assumption that a 500-ft section of boom can burn 5,000 bpd) is shown in Table 5-4.

Using the *in situ* burn removal capacity values for each region, and making some general estimates of the time required to move *in situ* burn resources from adjacent regions or distant regions into a specific region, it is possible to estimate the *in situ* burn removal capacity that could be implemented within each region to meet Tiers I, II, and III response criteria. *In situ* burn equipment must be mobilized and transported from one region to another, and assembled and deployed on-scene. Travel time estimates are made using the standard NSFCC logistics guidelines of 35 mph travel speed for ground transport, 113 mph (100 kts) for air transport, and 5 kts for sea travel. Estimated loading and unloading times during the transport process) are provided in Table 5-6.

Using the information in Tables 5-4 and 5-6, the total time required to move *in situ* burn resources over representative distances of 250, 500, 750, and 1,000 nmiles by land and air transport can be estimated (Table 5-7). Using these estimated transport times and accounting for the size of adjacent regions, distances between distant regions (e.g., Alaska and the Pacific Northwest), and specific distribution of *in situ* burn resources within these various regions, some conservative estimates can be made regarding the ability to augment *in situ* burn removal capability at Tiers I, II, and III by moving *in situ* burn resources from adjacent and distant regions to the region in question.

TABLE 5-6. Unload Times (in Hours) for Equipment Transportation.

LOADING OPERATION	GROUND TRANSPORT	AIR TRANSPORT
Acquire truck	1	1
Load equipment on truck	1	1
Transport to airport	N/A	2
Transfer truck to plane	N/A	1
Transfer plane to truck	N/A	1
Transport from airport to vessel load out port	N/A	2
Transfer from truck to vessel	1	1

TABLE 5-7. Transport and Deployment Times (in Hours) for *In Situ* Burn Equipment for Various Distances from Storage Location.

TRANSPORT COMPONENT	250 NMILES		500 NMILES		750 NMILES		1,000 NMILES	
	LAND	AIR	LAND	AIR	LAND	AIR	LAND	AIR
Load/unload	3	9	3	9	3	9	3	9
Transport	7	2.2	14	4.5	21.6	6.6	29	8.8
Deployment to spill scene	10	10	10	10	10	10	10	10
TOTAL	20	21.2	27	23.5	34.6	25.6	42	27.8

Table 5-8 summarizes this *in situ* burn resource augmentation capability by listing the total burn capability that could be realized in each region at Tiers I, II, and III by importing resources from other regions. The values at Tiers I, II, and III generally reflect the ability to transport *in situ* burn resources between adjacent regions within 24 hours (Tier I) for travel distances less that 500 nmiles, and within 48 hours (Tier II) for travel distances less than 1,000 nmiles. For Tier III, the values in Table 5-8 reflect the ability to transport all resources on the East Coast or West Coast to a spill scene located on that respective coast within 72 hours, as well as transport resources by air between the West Coast, Hawaii, and Alaska within 72 hours.

Table 5-8 embodies some inherent assumptions and constraints. For instance, it is assumed that the CCC's assets are readily available for transport to Region IV – U.S. Caribbean (Puerto Rico and U.S. Virgin Islands), but not immediately available to other locations in the southeastern United States. It also assumes that fire-resistant booms owned by MSRC (which represents a significant portion of the total boom available in the contiguous 48 states) will be made available to non-member companies upon request. In general, the augmented *in situ* burn removal capacities in Table 5-8 represent conservative estimates. With some prior planning and favorable weather and logistics, it is possible that *in situ* burn removal capacities, particularly at Tiers II and III, would be even larger. In addition to having available *in situ* burn resources, the overall capability to implement the anticipated *in situ* burn oil removal capacity depends on its use being approved, and a spill being amenable to *in situ* burning.

Table 5-8 shows that the *in situ* burn removal capability varies significantly around the country. Alaska has the highest removal capacity, with *in situ* burn capacities of 35,000–50,000 bpd attainable in southern Alaska (Cook Inlet and Valdez) at Tier I, and up to 100,000 bpd on the North Slope. Removal capacities of 300,000 bpd are attainable in Alaska at Tier II. Removal capacities of 5,000 bpd can be attained on the East and Gulf Coasts at Tier I, and up to 10,000–20,000 bpd at Tier II. *In situ* burn capabilities on the West Coast are limited, with no Tier I capability in California, and only 5,000 bpd available at Tier II. It is clear, however, that these capacities could be augmented with several additional, strategically placed fire-resistant boom kits.

TABLE 5-8. Estimated *In Situ* Burn Removal Capacity by U.S. Coastal Region* at Tiers I, II, and III.

REGION*	*IN SITU* BURN REMOVAL CAPACITY (BPD)		
	TIER I (24 HOURS)	TIER II (48 HOURS)	TIER III (72 HOURS)
I – New England	0	10,000	30,000
II – Northeast	5,000	10,000	30,000
III – Middle Atlantic	5,000	10,000	30,000
IV – Southeast	5,000	20,000	30,000
IV –U.S. Caribbean	5,000	20,000	30,000
VI – Gulf Coast	5,000	10,000	25,000
IX – California	0	5,000	105,000
X – Pacific Northwest	5,000	5,000	105,000
Alaska	50,000	300,000	300,000
Oceania	5,000	5,000	110,000

Note: bpd, barrels per day.

* Federal (EPA) regions are defined as follows: I – New England (Connecticut, Rhode Island, Massachusetts, New Hampshire, Vermont, Maine), II – Northeast (New York, New Jersey), III – Middle Atlantic (Delaware, Maryland, Virginia), IV – Southeast (North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi), IV – U.S. Caribbean (Puerto Rico, U.S. Virgin Islands), VI – Gulf Coast (Louisiana, Texas), IX – California, X – Pacific Northwest (Oregon, Washington), Alaska, and Oceania (Hawaii, Guam).

5.6 CURRENT POLICY FOR *IN SITU* BURN IMPLEMENTATION

Having the resources available to conduct *in situ* burning does not mean that an *in situ* burn operation will be initiated promptly and successfully. To be implemented, *in situ* burning must be approved by the Federal On-Scene Coordinator (FOSC) in accordance with the National Contingency Plan (Sec. 300.910) and applicable Regional Contingency Plans (RCPs), and must be part of the overall response strategy as evidenced by including *in situ* burning as a viable countermeasure in ACPs and vessel and facility response plans.

The possibility of *in situ* burn approval can be assessed from pre-approval policies in place in each region, which have evolved significantly since 1993 (Walker *et al.,* 1999). The current pre-approval guidelines are summarized in Table 5-9 for each region discussed above (see also Figure D-2 in Appendix D). Current policy is generally categorized as follows (SEA, 1998):

- **Case-By-Case Approval.** Use of *in situ* burning for each incident requires the FOSC to consult with federal agencies designated in the National Contingency Plan and obtain concurrence of the EPA and affected state(s), including the state Air Quality Board.

TABLE 5-9. *In Situ* Burn RRT Guidelines by U.S. Coastal Region* (as of December 1997).

REGION*	CURRENT CRITERIA
I – New England	Expedited approval for all states except Connecticut. Case-by-case approval for Connecticut.
II – Northeast	Pre-approval at > 3 nmiles from shore for New York and New Jersey.
III – Middle Atlantic	Pre-approval at > 3 nmiles from shore for Maryland and Virginia. Pre-approval pending (draft agreement being reviewed) for Delaware
IV – Southeast	Pre-approval at > 3 nmiles from shore except for Florida coast, where pre-approval specifies > 9 nmiles from shore.
IV – U.S. Caribbean	Pre-approval at > 3 nmiles from shore.
VI – Gulf Coast	Pre-approval at > 3 nmiles from shore.
IX – California	Case-by-case approval. Draft pre-approval agreement signed for > 35 nmiles from shore, evaluating agreement for > ½ nmile from shore.
X – Pacific Northwest	Pre-approval at > 3 nmiles from a population center.
Alaska	Pre-approval at > 1–6 nmiles from a population center depending on specific location and season
Oceania	Pre-approval subject to prevailing winds, populations, sensitive resources.

Note: RRT, Regional Response Team; nmiles, nautical miles.

* Federal (EPA) regions are defined as follows: I – New England (Connecticut, Rhode Island, Massachusetts, New Hampshire, Vermont, Maine), II – Northeast (New York, New Jersey), III – Middle Atlantic (Delaware, Maryland, Virginia), IV – Southeast (North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi), IV – U.S. Caribbean (Puerto Rico, U.S. Virgin Islands), VI – Gulf Coast (Louisiana, Texas), IX – California, X – Pacific Northwest (Oregon, Washington), Alaska, and Oceania (Hawaii, Guam).

Source: Adapted from SEA (1998).

- **Expedited Approval.** Use of *in situ* burning requires the FOSC to obtain concurrence of several key people, usually representatives from EPA, NOAA, Department of Interior, and affected state(s). Expedited approval agreements limit the quantity and type of information that the FOSC must provide to obtain concurrence, and limit the time agencies may take prior to approving or disapproving use. Expedited approval may be limited to a particular geographic area, distance from shore, water depth, or season within a given area. Expedited approval lasts only for a set period of time; RRT approval must be renewed thereafter to continue burning.

- **Pre-Authorization.** *In situ* burn use for each incident is at the discretion of the FOSC without further approval by other federal or state authorities. Pre-authorization zones are generally limited by particular geographic area, distance from shoreline, water depth, or season. Most pre-approvals are limited to the first 4–8 hours of burning. After this period, the FOSC must inform RRT of progress and receive an extension of the approval to continue burning.

As indicated in Table 5-9, *in situ* burning is now pre-authorized, with certain stipulations, at 1–9 nmiles from shore in all regions except I – New England and IX – California. Revised approval guidelines are currently under consideration in both these regions, which should

lead to pre-authorization policies being adopted within the next year or so that are consistent with the other regions. This is a dramatic policy shift since 1993, when pre-authorization policies were in place in only two regions: Alaska and VI – Gulf Coast.

Paralleling the formulation of regional policies by RRTs, *in situ* burning as a countermeasure is being included in ACPs as a viable response option for specific scenarios. This is the case for locations in Region VI – Gulf Coast (e.g., Morgan City and New Orleans) and Alaska (e.g., Cook Inlet and Prudhoe Bay). In addition, several Area Committees in Alaska, Washington, Louisiana, and Texas are now including *in situ* burning as a part of preparedness exercises.

5.7 CONCLUSIONS AND RECOMMENDATIONS

Table 5-10 summarizes the information provided in previous sections on *in situ* burn removal capability at Tiers I, II, and III, and current approval criteria. It also provides insight on the probability of a spill occurring in each region that would be amenable to *in situ* burning. This probability is based on the number of spills that have occurred in past years that met *in situ* burn criteria as investigated by Kucklick and Aurand (1995) (assuming a potential implementation as close as ¼ nmile from shore) and updated in this Caps review as presented in Chapter 2. Alaskan spills also have been added, although they were not included in Kucklick and Aurand (1995). The number of spills in each region that were amenable to *in situ* burning are tabulated in Table 5-10. A subjective determination is made of the probability that an *in situ* burn operation will be implemented in a particular region based on the overall removal capacity, current approval policy, and past history on amenable spills (denoted as high, moderate, and low).

In reviewing the overall status of *in situ* burn response capability in Table 5-10, several conclusions can be drawn with respect to the potential for implementing *in situ* burning around the country. *In situ* burning is only directly relevant to "all except rivers and canals, and Great Lakes" since *in situ* burning as a primary countermeasure in areas where oil might be spilled into a river or canal is unlikely (although by no means strictly prohibited). Likewise, the RRT in Region V – Great Lakes has adopted a policy specifying case-by-case approval for *in situ* burning. Application in the Great Lakes is likely to be limited by proximity to shore and population centers, and infrequent occurrence of *in situ* burn candidate spills. Burning in rivers and canals and the Great Lakes will most likely be used as a secondary countermeasure to mechanical recovery or as a shoreline removal technique involving limited quantities of oil. *In situ* burning is most likely to be used in open coastal locations or offshore. At present, *in situ* burning is most likely to be used in two regions: Alaska and Region VI – Gulf Coast. In the western Gulf of Mexico (Region VI), the availability of a moderate removal capability, favorable pre-approval policy, and higher incidence of *in situ* burn candidate spills makes *in situ* burn implementation potential high. In Alaska, the large removal capacity, favorable burn approval policy, and dependence on *in situ* burning for spill response in ice makes *in situ* burn implementation potential high. In other U.S. coastal regions, with the exception of California and Hawaii, the implementation potential is generally moderate.

TABLE 5-10. Overview of *In Situ* Burn Status By U.S. Coastal Region*.

REGION*	OIL REMOVAL CAPACITY (BPD)			APPROVAL POLICY	PAST *IN SITU* BURN SPILLS	
	TIER I	TIER II	TIER III		1,000 BBLS 1973–1994	1,000 GALS 1993-1998
I – New England	0	10,000	30,000	Case-by-case approval	3	2
II/III– Northeast/Middle Atlantic	5000	10,000	30,000	Pre-approval > 3 nmiles	0	5
IV – Southeast/U.S. Caribbean	5,000	20,000	30,000	Pre-approval 3–9 nmiles	3	14
VI – Gulf Coast	5,000	10,000	25,000	Pre-approval 3 nmiles	29	39
IX – California	0	5,000	105,000	Pre-approval > 35 nmiles	2	10
X – Pacific Northwest	5,000	5,000	105,000	Pre-approval > 3 nmiles	1	7
Alaska	50,000	300,000	300,000	Pre-approval 1–6 nmiles	N/A	6
Oceania	5,000	5,000	110,000	Pre-approval	2	7

Note: bpd, barrels per day; bbls, barrels; nmiles, nautical miles.

* Federal (EPA) regions are defined as follows: I – New England (Connecticut, Rhode Island, Massachusetts, New Hampshire, Vermont, Maine), II/III – Northeast (New York, New Jersey)/Middle Atlantic (Delaware, Maryland, Virginia), IV – Southeast (North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi)/U.S. Caribbean (Puerto Rico, U.S. Virgin Islands), VI – Gulf Coast (Louisiana, Texas), IX – California, X – Pacific Northwest (Oregon, Washington), Alaska, and Oceania (Hawaii, Guam).

With respect to augmentation of the Caps requirements for vessels and facilities as stipulated in 33 CFR 155 and 33 CFR 154, the analysis in this chapter leads to the following conclusions:

1. Technology and techniques to conduct *in situ* burning have matured in the past few years. Fire-resistant booms are being tested and improved, ignition systems have been perfected, and instruments and procedures to monitor emissions have been fully developed and tested. In addition, the NOBE experiment in 1993 has verified the operational feasibility and environmental soundness of *in situ* burning as a countermeasure.

2. Equipment availability has improved significantly, with new designs being developed, tested, and marketed, and a substantial amount of equipment has been added to the national inventory since 1993. As reflected in Table 5-10, there is enough *in situ* burn equipment in most regions to provide an *in situ* burn removal capacity of at least 5,000 bpd at Tier I, 10,000 bpd at Tier II, and 30,000 bpd at Tier III. Regions IX – California and X – Pacific Northwest also could attain this capacity with the strategic placement of one or two more fire-resistant boom units. The revised Caps should ensure maintenance of this current capability in regions where it exists and encourage augmentation in other regions. This is particularly true for Regions I – New England, VI – Gulf Coast, and IX – California, where *in situ* burn candidate spills are more likely to occur, but current resources are limited.

3. In most coastal regions, RRTs are becoming more inclined to approve *in situ* burning with a pre-approval at distances greater than 1–6 nmiles offshore. Memoranda of Understanding (MOUs) are being negotiated in other regions (notably Region IX – California) that would lessen the *in situ* burn restrictions.

In situ burning should be encouraged, especially in waters subject to heavy icing, because:

- There are spill situations that preclude the use of mechanical recovery or dispersants (e.g., oil trapped in ice) such that burning may be the only appropriate option.

- There are spill situations, such as continuous discharge from a sunken or grounded vessel, where *in situ* burning in close proximity to the source may be the most effective removal option.

- In large, offshore spills, an *in situ* burn capability would relieve some of the pressure on responders to provide sufficient temporary and permanent recovered oil storage.

The USCG should encourage further development of the technology and maintenance of existing *in situ* burn removal capabilities. The Caps regulations should encourage vessel and facility plan holders that operate in waters where *in situ* burning pre-authorization or expedited approval exists to maintain an *in situ* burn removal capacity of 5,000 bpd at Tier I; 10,000 bpd at Tier II; and 10,000 bpd at Tier III, by allowing a credit against the mechanical

recovery caps requirements at these levels. The credit is held at 10,000 bpd for Tier III because of the limited window of opportunity for use after 72 hours for several reasons:

- ISB involves the coordinated movement of multiple surface vessels and spotter/monitoring aircraft. It also involves special health and safety considerations. The result is that conventional mechanical recovery operations are severely restricted in the vicinity of ISB operations.

- Coordinating the efficient and effective movement of more than one or two ISB operations simultaneously would overburden incident command and control capabilities.

- The ISB capabilities cited in this report are optimistic and depend on "optimum" weather and oceanographic conditions.   .

- The potential opportunities for ISB use represent only a subset of the spills where mechanical recovery is appropriate. Allowing and offset of greater than 10,000 bbls would erode the adequacy of mechanical recovery capability in all spills. As the data in this report indicate, even if all recommended increases are adopted, the combined mechanical recovery, dispersant and ISB caps still fall short of fully ensuring response to projected worst case scenarios in most offshore and nearshore areas.

Additional considerations regarding the proposed offset include:

- This credit should only be offered if mechanical recovery Caps increase by 50% over the next 5 years.

- Because current *in situ* burn booms are estimated to have a 10-hour survival rate, plan holders would have to ensure five complete burn boom packages available by contract to receive the full offset.

- If research and development on stainless steel and/or water-cooled booms demonstrate significant improvement in boom survivability, it is assumed that the number of packages required available by contract may be reduced.

Tying a credit to existing pre-authorization agreements targets those areas where the technique is most likely to be used. Also, areas of most probable use are automatically targeted, and are clearly within reach given the current technology and equipment availability. It provides incentive for RRTs to finalize policies for pre-authorization and expedited approval in areas where they are still in draft form, and sets aggressive criteria for *in situ* burn use (e.g., less than 3 nmiles offshore throughout the country). This will also provide an incentive to vessel and facility plan holders to further develop an *in situ* burn capability while maintaining a balanced response capability consisting of mechanical recovery, dispersants, and *in situ* burn resources as applicable.

How far have **in situ** *burn techniques and equipment, as well as supporting spill surveillance technology, advanced since the Caps were formulated? Have these techniques and equipment been operationally tested and proven?*

- The technology to support *in situ* burning has evolved rapidly. Advances in GPS and computer technology have improved the ability to compile and display real-time surveillance data.

- Fire-resistant boom development has accelerated to handle the limited service life of booms exposed to at-sea burns.

- Igniter technology to support *in situ* burning has been fully developed and operationally verified.

- The technology to support air quality monitoring during *in situ* burn operations has developed in parallel with the *in situ* burn research efforts, and is readily available to support *in situ* burn operations in the field.

- Both the equipment and procedures to conduct *in situ* burning at sea have been tested and verified in full-scale, offshore test burns.

Are modern **in situ** *burn equipment and systems readily available? What oil removal capability is represented by current inventory? How fast can pre-staged fire-resistant booms be transported to specific regions, and what oil removal capacity does this provide in each region at Tiers I, II, and III?*

- The number of booms on the market, and the level of performance testing undertaken, has increased significantly in the past few years.

- Ignition systems and igniters are readily available throughout the country.

- Under favorable spill conditions, a 500-ft section of boom can be used to remove 5,000 bpd of oil from the water surface. Based on this figure, this analysis shows that there is a significant *in situ* burn oil removal capability already in place around the country.

- Because of the inherent transportability of fire-resistant boom sections and Helitorch systems, resources can be easily moved from one region to another and quickly deployed.

How has the policy on **in situ** *burn implementation changed over the past few years, as reflected in current agreements between federal and state agencies regarding its use?*

- *In situ* burning is now pre-authorized, with certain stipulations, at 1–9 nmiles from shore in all coastal regions except for Regions I – New England and IX – California. Revised federal and state agreements are currently under consideration in both these regions, which should lead to a pre-authorization policy being adopted within the next year. This is a dramatic policy shift since

1993, when pre-authorization guidelines were in place in only two regions: Alaska and Region VI – Gulf Coast.

Is including a requirement and/or offset for an** in situ **burn removal capability practicable in light of the advances in technology, market availability, overall distribution of** in situ **burn resources around the nation, and current (and projected) Regional Response Team (RRT) policy for** in situ **burn implementation?

- *In situ* burning is most relevant to the areas designated as "All except rivers and canals, and Great Lakes" (per 33 CFR 155 and 33 CFR 154) because *in situ* burning as a countermeasure in areas where oil might be spilled into a river or canal is unlikely (although by no means strictly prohibited).

- It is clear that the technology and techniques to conduct *in situ* burning have reached maturity in the past few years, and the availability of equipment has improved significantly with new designs being developed, tested, and marketed. There is enough equipment in all regions except Region IX – California to provide an *in situ* burn removal capability of 5,000 bpd at Tier I, 10,000 bpd at Tier II, and 10,000 bpd at Tier III.

- The revised Caps regulations should encourage maintenance of this current capability in regions where it exists, and encourage augmentation in other regions. A straightforward and practicable mechanism for accomplishing this is to allow an offset using *in situ* burn removal capability against mechanical recovery Caps in regions where *in situ* burn pre-authorization is in place.